Economic Evaluation of Household Solid Waste Management in Jakarta, Indonesia

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Abstract

The largest stream of municipal solid waste in Indonesia flows from households. Because policy makers are concerned about municipal solid waste (MSW) management aspects, such as cost and collection rates, this article focuses on the economic aspects of household solid waste management systems. The economic analysis was performed against the background of five predetermined MSW management scenarios. This study suggests that communal composting has the highest potential, as it has the highest cost:benefit ratio. However, the present communal composting rates are notably low, and several constraints must be overcome for the future development of on-site composting systems.

1. Introduction

Household waste contributes as the largest share in municipal solid waste in Indonesia, followed by traditional markets (Aye and Widjaya, 2006). Solid waste management (SWM) usually involves both the formal and the informal sectors. In Indonesia, the formal sector includes municipal agencies and formal businesses, whereas the informal sector consists of individuals, groups and small businesses whose activities are not registered and not formally regulated. In solid waste activities, the informal sector refers to recycling activities that are conducted by scavengers (itinerant waste pickers), or waste buyers. (Sembiring and Nitivatta, 2010).

Prior studies (e.g. Bohma, Folzb, Kinnamanc, and Podolskyd, 2010; Aye and Widjaya, 2006; Sonneson, Bjorklund, Carlsson, and Dalemo, 2000; Reich, 2005) have discussed and estimated the impact of economic factors in domestic solid waste management. They have linked household participation and behaviour to economic assessment with the concept of willingness to pay (e.g. Purcell et al, 2010; Bruvoll et al, 2002; and Berglund, 2006) and discussed the role of economic factors in the feasibility of different socio-technological options or scenarios to be realised. The economic analysis of our study was performed against the background of five predetermined scenarios of MSW management. In addition to the Scenario 1 involving the use of a landfill, the proposed scenarios for this study include 25% landfilling, combined with communal composting (scenario 2), anaerobic digestion (scenario 3), centralised composting (scenario 4), and landfill gas for energy generation (scenario 5). This study also aims to estimate the potential revenues from the sorted recyclable materials. It additionally analyses the householders' willingness to pay for other people to sort their waste with the assumption that the government authorities demand at-source waste sorting.

2. Scenarios for household solid waste management

Waste management options that would lower CH_4 and N_2O emissions would be regarded favourably (McDougall et al., 2001). Landfill gas consists primarily of methane and carbon dioxide, both 'greenhouse gases' and has therefore become significant in the debate over global warming and climate change. Methane is considered to be responsible for approximately 20% of the recent increase in global warming (Lashof and Ahuja, 1990), and landfills are thought to be a major source of methane. The Clean Development Mechanism (CDM) scheme allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol to implement an emission-reduction project in developing countries. Such projects can earn saleable certified emission reduction (CER) credits, each equivalent to one tonne of CO_2, which can be counted towards meeting Kyoto targets (UNFCCC, 2011). The CDM project activity might involve, for example landfill gas to energy (waste-to-energy) and anaerobic digestion, which revenues are generated from the greenhouse gas saving.

The objective of this study is to evaluate the economy of each of the waste management process scenarios. The scenarios were defined based on the existing and feasible treatment methods for household waste (e.g. IPCC (2006), Oosterveer and Spaargaren (2010), and Aye and Widjaya (2006)), whereas the fraction of waste treated per scenario – both the organic and inorganic fractions – were decided upon using figures found in the literatures, such as Japan Bank for International Cooperation (2008) and Yi, Kurisu, and Hanaki (2011).

The largest fraction of organic waste (75%) is treated with the waste treatment method in each scenario, while the rest of organic wastes that cannot be treated are disposed in the landfill. Prior to defining the scenarios, field observations were conducted. The following flow chart for the waste management system in Jakarta is obtained based on the observations:

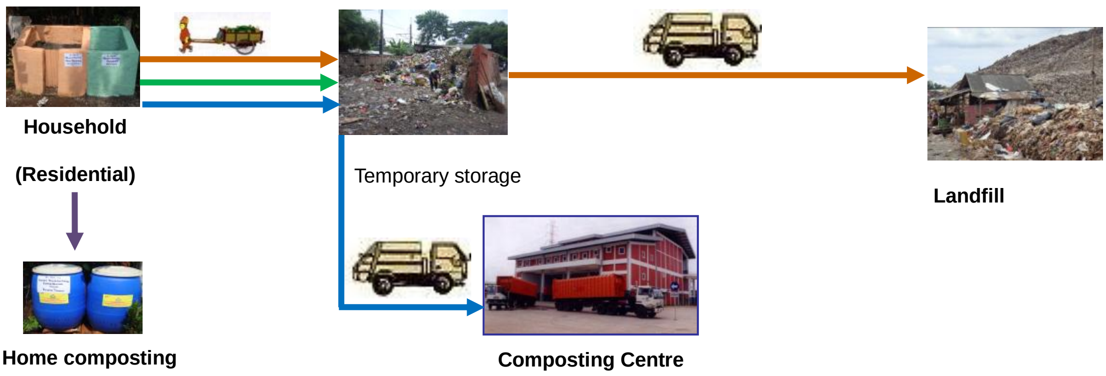

Fig. 1. Flow chart of the household solid waste management system in Jakarta

Temporary storage is established to reduce the hauling distances for collection trucks, thus lowering transportation costs. It is categorized as depot, which is an area that is also used to store hand carts to transfer the waste to the garbage trucks. The depot also includes a base for handcarts that is usually located on the side of the road, tranship site, and waste collection point made of concrete. There are 1,478 temporary storages available in Jakarta (Cleansing Department, 2010). On the temporary storage, the wastes are transferred to waste trucks, which are operated by manual labour or shovel loader. The wastes are then transported to the composting centres or landfill. There is no intermediate treatment at these temporary storages; however transport efficiency to the disposal and composting site is increasing. According to the JETRO report (2002), operation of the temporary storages increases the effectiveness of collection vehicles from 1.7 to 3 trips per day. (Pasang, 2007). This is due to the fact that the wastes that are pooled in the temporary storages are easily collected and transported to the disposal site, rather than collecting the wastes from various points that would otherwise reduce the efficiency of collection.

The system boundaries and scenarios proposed in this study are as follows:

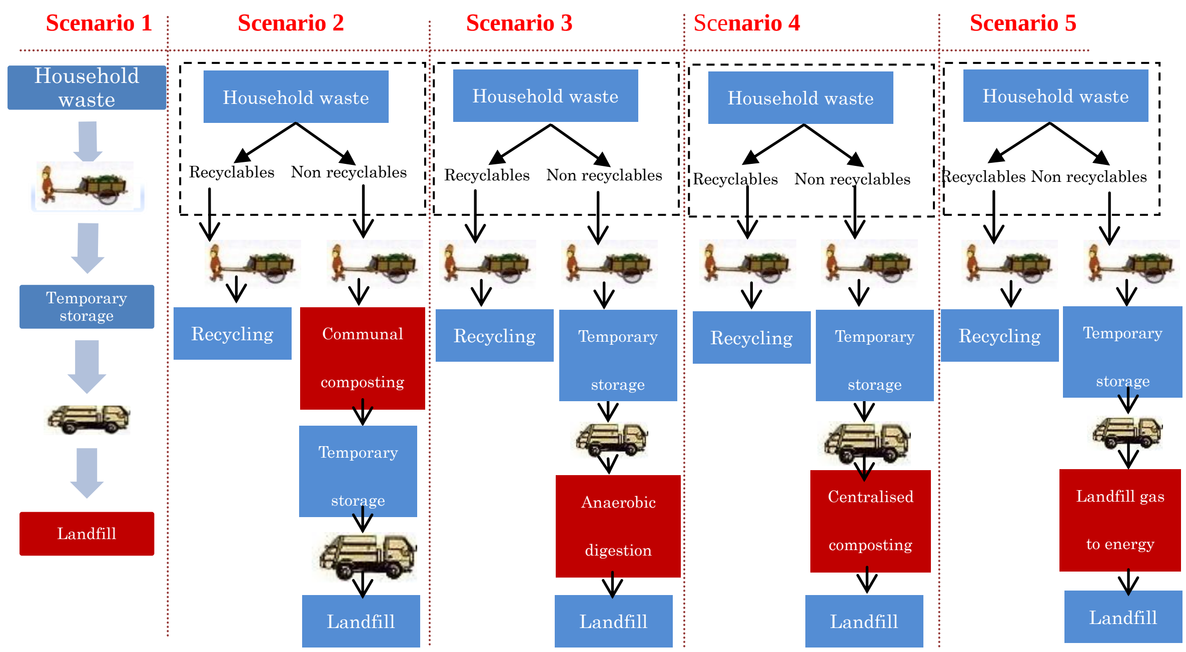

Fig. 2 System boundaries and scenarios for waste management

This study compares five scenarios (see Fig. 2) for handling waste from households in Jakarta. The current operation of landfilling (open dumping) was included in the business-as-usual (BAU) of Scenario 1 for comparison. As incineration of wastes is a largely unfeasible option in non-OECD countries due to cost and often unsuitable waste composition (UNEP, 2010), the incineration scenario is not included in this study.

Table 1 provides an overview of the elements of waste in each scenario. The table shows the fractions of waste treated using specified modes of treatment. The fraction of waste treated per scenario is decided upon with the help of figures found in the literatures, such as the Japan Bank for International Cooperation / JBIC (2008), Yi, Kurisu, and Hanaki (2011), and Oberlin (2011). The largest fraction of organic waste (75%) is treated with the waste treatment method or technology characteristic for the particular scenario, while the rest of organic wastes that cannot be treated are disposed in the landfill.

Table 1. Fraction of waste treated per scenario

Waste types	Scenario 1	Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	L	CC	L	AD	L	CE	L	LFE	L
Organic waste (%)	100	75	25	75	25	75	25	75	25
Inorganic waste (%)		0	100	0	100	0	100	0	100

L: landfill. CC: communal composting. AD: anaerobic digestion. CE: composting center. LFE: landfill gas to energy.

3. Methodologies and Results

3.1. Estimation of cost and benefits for each scenario

The financial and economic analysis refers to prior study by Aye and Widjaya (2006). The costs and benefits of each of the waste management scenarios are estimated by processing the information obtained from surveys with the landfill administrator, communal composting officers, Cleansing Department, and householders. The study makes use of secondary data that are provided by the government and by the landfill gas-to-energy-generation administrator. These sources provided (sometimes confidential) information, such as landfill operation cost breakdowns and financial aspects of the certified emission reduction rights from the methane gas flaring project.

The estimation also takes into account waste transportation-related costs, such as the wages for transporting waste from households to temporary storage and those for transporting waste from temporary storage to the waste treatment or disposal facility (US$ per annum). The data were obtained from surveys with the waste transporters.

The total transportation cost is estimated by:

$$\mathbf{C_T} = \Sigma (F_{con} . F_i) + (W_H . H_T / H_S) + (W_T . T_T)$$

where

C_T = Cost of transportation

F_{con} = Fuel consumption (liter per annum)

F_i = Cost of fuel i (US$ per liter)

W_H = Wage of waste transporters from households to temporary storage (US$ per person per annum)

T_H = Number of waste transporters from households to temporary storage

W_T = Wage of wage transporters from temporary storage to waste treatment / disposal facility (US$ per person per annum)

T_T = Number of waste transporters from temporary storage to waste treatment / disposal facility

H_T = Total number of households

H_S = Total number of households served per waste transporter

The wages are estimated from the survey with waste transporters. The average wage of waste transporters from household to temporary storage is US$ 1,115 per person per annum, whereas the average waste transporters from temporary storage to waste treatment or disposal facilities is US$ 1,501. The difference in waging is due to the different waging system, of which the waste transporters from temporary storage to the waste treatment or disposal facilities have official contracts from the Cleansing Department. The waste transporters from households to temporary storage typically have informal contracts with the neighbourhood associations and the wage is lower than the official contract holders.

The estimations are based on the actual costs and revenues for the whole lifecycle for each scenario. The revenues from recycling of recyclables are not incorporated in this estimation. However, it is estimated separately in the subsequent subchapter that presents the estimations of revenues potential from recycling of sorted recyclable waste. The waste disposal costs (known as tipping fees) savings from the savings of treated waste for each scenario that would otherwise be disposed at the landfill are taken into account in the estimation. Currently the tipping fee at Bantar Gebang is IDR 103,000 or US$ 12 per tonne of waste disposed.

The estimation results of costs and benefits for each scenario are presented in Table 2.

Table 2. Comparison results of cost and benefits for 5 scenarios

	Scenario 1 (Landfill)	**Scenario 2 (Communal composting)**	**Scenario 3 (Anaerobic digestion)**	**Scenario 4 (Central composting)**	**Scenario 5 Landfill gas to Energy**

Quantity of waste (tonne per day)	6,000	200	250	1,000	298
Quantity of waste (tonne per annum)	2,190,000	73,000	91,250	365,000	108,919
Annual rate	6.5%				
Investment cost:					
Land acquisition	1,852,941	2,575	2,670,692	5,150,882	1,291,787
Construction	62,890,366	23,529	14,803,638	7,181,643	28,356
Equipment	300,176	1,765	12,861,040	9,266,182	1,342,071
Planning, design and engineering	9,069,641	88	8,435,609	3,319,321	95,275
Total investment cost	74,113,124	27,958	38,770,978	24,918,028	2,757,488
Operation and maintenance cost (per annum)	317,698	12,395	6,767,334	6,557,486	356,560
Transportation cost	1,919,680	655,046	1,919,680	696,141	1,919,680
Total cost	76,350,503	695,399	47,457,992	32,171,655	5,033,728
Revenue:		0	0	0	0
Compost production (tonnes per annum)		706	0	46,976	0
Selling price (per tonne)		118	0	40	0
Electricity production per annum (kWh)		0	20,070,912	0	17,849,000
Selling price (US$/kWh)		0	0.11	0	0.11
Total revenue and tipping fee savings (US$ per annum)		959,045	2,303,275	1,872,553	2,048,296
Revenue:cost ratio	0	1.4	0.05	0.1	0.4

At 1 US$ = 8,500 IDR

According to the estimations, communal composting of Scenario 2 has the highest potential in terms of the revenue:cost ratio. The second-best option is landfill gas to energy of Scenario 5. The third-best option is central composting (Scenario 4), followed closely by anaerobic digestion (Scenario 4). The worst potential is landfill (Scenario 1), which does not yield any revenues of products.

3.2. Benefits from greenhouse gas emission reduction and co-products for each scenario

For each of the waste treatment scenarios, the economic analysis in this study accounts for the benefits from both greenhouse gas (GHG) emission reduction and co-products, such as compost and electricity generation. The costs and benefits deriving from such externalities are not usually taken into account; therefore, this study accounts for CO_2 as a GHG emission reduction benefit and for the co-products generated by each waste treatment method, whereas other benefits are neglected. The equation to which the economic analysis is applied is as follows:

$$\mathbf{NPV_{cost}} = (I) + OM + T \left(\frac{1 - (1 + r)^{-t}}{r} \right)$$

$$\mathbf{NPV_{revenue}} = (R_p + R_{ghg}) \times \left(\frac{1 - (1 + r)^{-t}}{r} \right)$$

$$\mathbf{NPV_{benefit}} = NPV_{revenue} - NPV_{cost}$$

where:

I = the investment cost (US$)

OM = operation and maintenance cost (US$ per annum),

T = transportation cost (US$ per annum)

R_p = revenue of product (US$ per annum),

Rghg = revenue of greenhouse gas saving (US$ per annum)

r = discount rate (based on Aye, 2006)

t = project life time.

Greenhouse gas (GHG) emission savings were calculated in the previous study (Aprilia et al, 2011), in which the GHG emissions of each scenario were compared to the baseline scenario. The carbon price is US$ 12 per tonne CO_2 (UNFCCC, 2009). At the time of the study the price of grid electricity is on average about IDR 860 per kWh or US$ 0.1 per kWh. Comparisons of the externality of GHG savings for each of the waste treatment scenario in US$ per tonne are presented in Table 3.

Table 3. Comparison of the economic impact of the scenarios (in US$)

	Scenario 1 (Landfill)	**Scenario 2 (Communal composting)**	**Scenario 3 (Anaerobic digestion)**	**Scenario 4 (Central composting)**	**Scenario 5 Landfill gas to energy**
CO2 savings (kg/tonne waste)	0	461,000	498,000	461,300	489,906
Carbon price (US$/tonne CO2)	0	12			
Project life (year)	20				
Discount rate	6.37%				
NPV cost (US$/tonne)	75	373	4,302	878	876
NPV revenue (US$/tonne)	0	509	1,031	210	768
NPV benefit (US$/tonne)	0	136	-3,271	-668	-108
Revenue:cost ratio	0	1.37	0.24	0.24	0.88

The assumption used for anaerobic digestion scenario is that residues are not composted, but landfilled. In regards to the communal composting scenario, voluntary action is assumed. For the landfill gas to energy scenario, the amount of CH_4 produced is assumed as the same as the other scenarios with 60% collection efficiency.

Based on the estimation of the externality of greenhouse gas savings for each waste treatment scenario, communal composting (Scenario 2) has the highest potential as it has the highest revenue:cost ratio. It should however be noted that the communal composting activities that take place in Jakarta are of voluntary nature that employ voluntary labour with lower average wage compared to the regular labour wage. The costs for existing and common communal composting are also relatively low as simple composting techniques are applied. The costs for construction, equipment, O&M, planning, design, and engineering are much less than the other options, which accounts for the total investment cost. The economic data for communal composting was obtained from field survey and interview with the operator of the facility; therefore the data are of actual value.

Landfill for electricity generation (scenario 5) does not generate positive benefit; however it has better potential rather than anaerobic digestion and central composting scenario. The potential revenue from scenario 5 includes the revenue from GHG emission saving through Clean Development Mechanism scheme, as well as electricity generation. The price of electricity that can be sold to the grid is currently US$ 0.11 per kWh, which is an increase compared to in 2006 which was US$ 0.06/kWh. The implementation of this scenario should be accompanied by financial support by the government, particularly to cover the investment costs of equipment provision and land acquisition.

The centralised composting (scenario 4) is the third-preferred option, followed by anaerobic digestion (scenario 3). As waste in Jakarta are not sorted, the centralised composting becomes labour-intensive, particularly for manually sorting the organic and inorganic wastes. The type of machinery used for the centralised composting plant considered in this study is conventional windrow, which is manual and non-mechanical composting process.

With anaerobic digestion, it is the least profitable as it requires the highest investment cost for construction and equipment, as well as O&M cost. The revenues obtained from the implementation of this scenario are from the GHG saving with CDM scheme and electricity generation that are sold to the grid, as the case of scenario 5. Scenario 1 has the least cost; however it does not generate any revenues.

All of the options proposed in this study, except for the Scenario 1, suggested that at-source waste sorting by householders would be required. This approach minimises the need for manual and automated sorting within the waste treatment facilities and increases the effectiveness of the composting and digestion processes. If plastic and inorganic material is present in urban solid wastes during anaerobic digestion and landfill gas to energy generation, it causes the total gas production to decrease (Muthuswamy, S. et al., 1990).

3.3. Potential of revenues from recycling of sorted recyclable waste

In addition to the economic evaluation for each of the scenarios, this study also estimates the potential of revenues from sorted recyclable waste, based on the primary data of quantity of recyclable waste from households and selling prices of recyclable materials obtained from field survey. The revenue potential of these wastes is shown in Table 4.

Table 4. Revenue potential from recycling of recyclable waste in Jakarta

Waste categories	Sub categories	Average selling price (US$ per kg)	Average quantity sold per household (kg per month)	Revenue potential (US$ per year)
Paper and cardboard				
	Newspapers	0.17	3.57	14,684,065
	Magazine	0.21	1.75	8,869,442
	Carton boxes	0.25	4.43	27,130,412
Plastic				
	Refuse plastic sacks	0.33	1.00	8,121,364
	Plastic bottles	0.27	1.75	11,617,372
Metal		0.45	1.04	11,529,765
Glass		0.23	1.36	7,668,986
Textiles	Used clothes and fabrics	1.04	1.00	25,319,547
Total			**15.90**	**114,940,952**

Fig. 3 depicts the revenue potential from sub categories of sorted recyclable waste. It shows that the revenue potential is the greatest for carton boxes, followed by textiles, newspapers, and plastic bottles. Based on the field observation, there are a vast number of carton boxes that are sold by householders to scrap dealers and/or waste pickers. The types of carton boxes sold are milk boxes, disposable food boxes, instant noodle box containers, goods box containers, etc. People in Jakarta tend not to have subscriptions so newspapers and magazines. They instead prefer to purchase individual copies, read the newspapers in the office, watch the news on television, or through the internet.

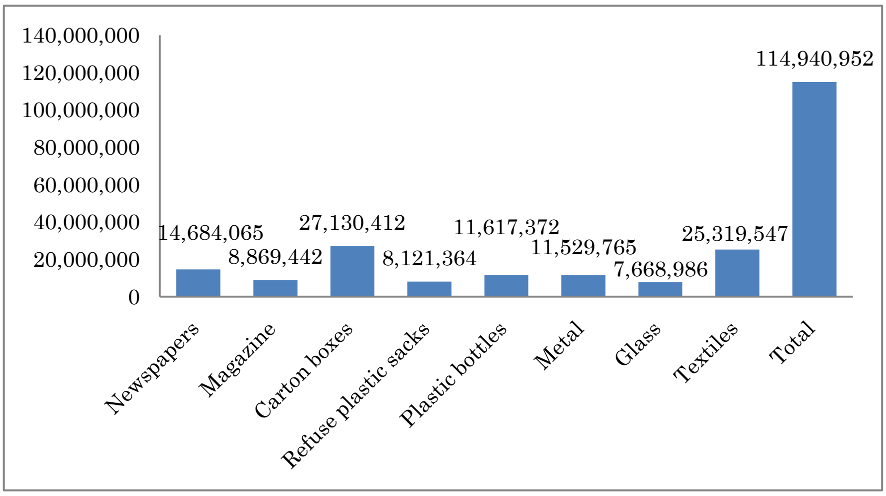

Fig. 3. Revenue potential from sorted recyclable waste (US$ per year)

Based on the estimation, the potential of revenues from the implementation of proper waste sorting to recover recyclable waste amounts to the total of nearly US$ 115 million per year.

4. Conclusions

This study extends the economic evaluation measuring the household solid waste management scenarios. According to the estimation, communal composting has the highest potential with the highest revenue:cost ratio. Theoretically, composting can be done at the communal level, at the temporary storage, or at the composting centre or landfill site. The costs of processing and transport, as well as the roles, perception, and responsibilities of households are arguably different. Despite the potential of communal composting, there are a high percentage of respondents indicating that there is no neighborhood composting. Thus, the present composting rates are very low compared to the composition of the waste.

There are several possible constraints regarding further application and expansion of communal composting, such as:

1) Land acquisition

The space of land that are being utilised for communal composting activities usually belong to a specific entity that dedicated the land as public space and later on being used for communal composting. For instance, the communal composting that takes place in Rawajati Jakarta used the land that belongs to the Indonesian ground forces and is dedicated for communal composting activities at no cost. Further application of communal composting throughout other areas would imply the need for open space to conduct the composting activities. In addition, the limited availability of open space in Jakarta would pose constraints particularly on the siting of the communal composting facilities.

2) Labour and waging system

The current activities of communal composting in Jakarta are employing voluntary labours with lower waging system. Further application of communal composting would require proper waging system at or above the regional minimum wage. The subsequent issue is on the marketing of compost products and to which extent the sales of the compost would be able to cover the operational cost including the provision of income for the labours. The current practice is that the compost products are being used by the community for personal usage. The tendency of urban residents for not conducting farming practices that would require compost and scarcity of land for farming would pose the question on marketing issues, for which marketing of product might have to be extended to neighboring areas of Jakarta.

3) Capacity of composting facilities

The capacity of communal composting is usually much smaller than the industrialised composting and the attempt to increase the capacity would be a challenge due to the limited compostable waste as feedstock and limited space of communal composting facility for which the composting activity takes place.

All of the options proposed in this study, except for the Scenario 1, suggested that at-source waste sorting by householders is required. However the majority of people in Jakarta do not sort their waste and the disposal of household waste is mixing organic, non organic, hazardous waste, bulky waste. Waste sorting tends to take place outside of the home, by waste transporters and manual labours at the temporary storage and waste treatment or disposal facilities.

Given the high potential revenues from the recovery of sorted recyclable waste in Jakarta with nearly US$ 115 million per year, proper sorting and management is required to prevent the loss of valuable materials at the landfill. It would also lead to waste reduction that decrease the amount of waste disposed at the landfill.

Promotion of at-source waste sorting is important; however appropriate end-of-pipe technologies for the treatment of municipal solid waste are also required. This study already identified feasible technologies with the order of cost-efficiency that can be considered for further implementation. Communal composting is found to have the highest potential as it has the highest revenue:cost ratio. However there are challenges such as the issues on land availability, labour and waging system, and capacity of composting facilities. The second preferred option is landfill gas to energy scenario, followed by central composting and anaerobic digestion. However it should be noted that the operation of landfill gas to energy, central composting and anaerobic digestion require substantial financial support from the government, particularly to cover investment and O&M costs. The financial support is regarded as the costs for municipal waste treatment that is borne by the government of Jakarta.

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